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UNITED STATES DEPARTMENT OF AGRICULTURE

In Cooperation with the
North Dakota Agricultural Experiment Station

DEPARTMENT BULLETIN No. 1293

Washington, D. C. ▼ April, 1925

TILLAGE AND ROTATION EXPERIMENTS AT DICKINSON, HETTINGER, AND WILLISTON, N. DAK.

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INTRODUCTION

This bulletin presents a summary of the results of tillage and rotation experiments conducted in western North Dakota by the Office of Dry-Land Agriculture Investigations of the Bureau of Plant Industry in cooperation with the North Dakota Agricultural Experiment Station at the latter's substations at Dickinson, Hettinger, and Wil-

[1] The Office of Dry-Land Agriculture Investigations was organized in 1905, with E. C. Chilcott in charge, who planned this work and continues to direct it. The men who have been in charge of the work at the stations covered by this report are as follows: At Dickinson, O. J. Grace, 1907–1909; J. C. Thysell, 1910–1918; and the writer since 1919. At Hettinger, H. C. McKinstry, 1911–1914; A. J. Ogaard, 1915–1917; and U. J. Downey, 1918–1922. At Williston, W. O. Whitcomb, 1909–1912; A. J. Ogaard, 1913–14; and C. H. Ruzicka, 1915–1920. Each of these men has contributed to this bulletin by keeping the necessary records and writing annual reports. John S. Cole, Agronomist, has aided by revising the manuscript.

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liston. The results of closely coordinated work conducted by the office mentioned at 21 other stations on the Great Plains have been of great assistance in interpreting the data.

The experiments at Dickinson were started in 1907 and have not been interrupted. They were extended in 1923 to obtain information on problems that have assumed importance and were not covered in the original plans. The experiments at Hettinger were started in 1911 and continued through 1922. Those at Williston were begun in 1909 and continued through the crop year of 1920. A part of the Williston substation was irrigated, but these experiments were on dry land located above the ditch.

At all three stations the first crop grown in these experiments was on virgin soil. Preparations for the work were begun by breaking the native sod during the summer of the year preceding the one cited as the time when the experiments started. The first year's crop was on breaking, and all plats were uniform in preparation and treatment. The results of the first year, when all plats received uniform treatment, are included in the tables and discussions of average yields, but are not included in the tables of yields from which comparisons of different methods and treatments are made.

CLIMATIC CONDITIONS OF THE REGION

PRECIPITATION

The quantity and the distribution of the precipitation are similar at the three stations and are characteristic of the region in which they are located. The average precipitation for the year, the four months from April to July, the five months from April to August, the six months from April to September, and the proportions of the seasonal quantities to the whole are given in Table 1 for each of these stations and for Bismarck, N. Dak., and Moorhead, Minn. Bismarck is near the center of the State and Moorhead is just across the eastern State line from Fargo. The data are from published reports of the United States Weather Bureau and in each case bring the record from its beginning down to and including 1920.

The annual precipitation was 15.41 inches at Dickinson, 14.52 inches at Hettinger, 14.42 inches at Williston, 17.10 inches at Bismarck, and 23.62 inches at Moorhead. A relatively high proportion of the precipitation falls while crops are growing, a fact of great importance to the agriculture of the region. The average precipitation for the four months from April to July was 9.02 inches at Dickinson, 9.31 inches at Hettinger, and 8.11 inches at Williston. These quantities are 58.5, 64.1, and 56.2 per cent, respectively, of the annual precipitation at the three places.

In both the five-month period from April to August and the six-month period from April to September the precipitation was greatest at Dickinson, least at Williston, and intermediate at Hettinger.

Dickinson is favored the most and Williston the least in both the quantity and the distribution of the rainfall. The differences may, however, be due, in part at least, to differences in the lengths of the records.

TABLE 1.—*Average annual and warm-season precipitation at Dickinson, Hettinger, Williston, and Bismarck, N. Dak., and Moorhead, Minn., from the establishment of the Weather Bureau stations to 1920, inclusive*[1]

Station	Altitude (feet)	Length of record (years)	Precipitation						
			Annual (inches)	April to July		April to August		April to September	
				Inches	Percentage of annual	Inches	Percentage of annual	Inches	Percentage of annual
Dickinson	2,543	29	15.41	9.02	58.5	10.97	71.2	12.04	78.1
Hettinger	2,675	14	14.52	9.31	64.1	10.56	72.7	11.86	81.7
Williston	1,875	27	14.42	8.11	56.2	9.78	67.8	10.79	74.8
Bismarck	1,674	46	17.10	9.68	56.6	11.67	68.2	12.92	75.6
Moorhead	935	40	23.62	12.67	53.6	15.66	66.3	17.85	75.6

[1] U. S. Department of Agriculture, Weather Bureau. Summary of the climatological data for the United States . . . from the establishment of the stations to 1920, inclusive. Reprint of Section 31—Western North Dakota. 15 p. 1922.
——— ——— Summary of the climatological data for the United States . . . from the establishment of the stations to 1920, inclusive. Reprint of Section 57—Northern Minnesota. 15 p. 1923.

Although the average distribution of rainfall is favorable, any single year or period may so deviate from the average as greatly to affect crop yields. The annual precipitation at the Dickinson station during the period of the experiments ranged from more than 22 inches in 1914 to less than 9 inches in 1919. The June rainfall, which affects the yields of crops in general more than that of any other month, varied during the same period from more than 7 inches in 1914 to only slightly more than 0.5 inch in 1919.

EVAPORATION

The three stations vary but little in the quantity of water lost by evaporation from an open tank. The average evaporation for each month from April to September, inclusive, is given in Table 2. The amount increases from April to July, then decreases during August and September. The average evaporation for the six months was 32.689 inches at Dickinson, 33.368 inches at Hettinger, and 33.104 inches at Williston. The greatest range between years was at Hettinger, where a minimum of 25.495 inches was recorded in 1915 and a maximum of 44.653 inches in 1911.

TABLE 2.—*Average monthly and seasonal evaporation at Dickinson, Hettinger, and Williston, N. Dak., from April to September, inclusive, for the periods specified*

Station	Period of record	Evaporation (inches)						
		Apr.	May	June	July	Aug.	Sept.	Seasonal
Dickinson	1907 to 1923	3.683	5.007	6.189	7.052	6.427	4.331	32.689
Hettinger	1911 to 1921	3.997	5.061	6.451	7.331	6.360	4.168	33.368
Williston	1909 to 1918	4.146	5.599	6.376	7.145	6.070	3.768	33.104

[1] From records of the Office of Biophysical Investigations, Bureau of Plant Industry, U. S. Department of Agriculture.

TEMPERATURE

Temperatures at the three stations do not vary greatly. The mean annual temperature at Williston is 39.2° F., at Dickinson 40.3°, and at Hettinger 41.5°. The low average at Williston results from low winter temperatures, the summer temperatures being about equal.

The factors which affect crops most are the relatively cool summers and the low temperatures of winter. Low winter temperatures, frequently coupled with a dry soil, make the growing of winter grains except rye uncertain, whereas the cool summers are favorable to spring-grain production.

Killing frosts seldom affect grain crops at these stations, but corn, fruits, or other tender plants sometimes are injured by late-spring or early-fall frosts. The average period between the last

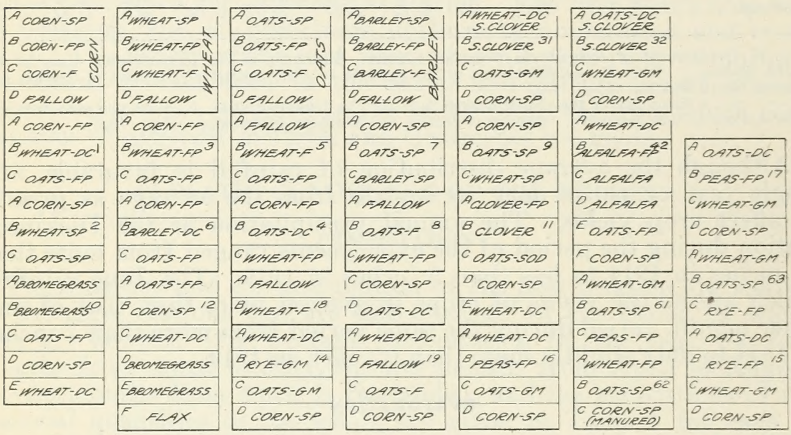

FIG. 1.—Diagram of the dry-land rotation field at the substation at Dickinson, N. Dak. The lettering shows the cropping in 1923. The following abbreviations are used to indicate the preparation: SP=Spring plowed, FP=fall plowed, DC=disked cornland, F=fallowed, and GM=green manured

frost of spring and the first frost of fall is 112 days both at Dickinson and Hettinger and 126 days at Williston. This does not mean, however, that plant growth is limited to these periods, as all but the most tender vegetation may survive temperatures several degrees below freezing. The longer frost-free period at Williston is accounted for by the fact that the altitude of this station is only 1,875 feet, whereas that of Hettinger is 2,675 feet and Dickinson 2,543 feet.

SOILS

The soils of the stations are typical of the good farm lands of the area. They are described as dark-brown loams, varying in texture from fine sand to clay. Like other soils of the area, they are high in fertility and characterized by a definite lime-carbonate accumulation at a depth of from 14 to 16 inches. The soil at Williston is comparatively light, that at Dickinson is intermediate, and that at Hettinger heavy. In a reconnaissance soil survey of western North Dakota[2] the

[2] Lapham, M. H., and others. Soil survey of western North Dakota. U. S. Dept. Agr., Bur. Soils, Field Oper., 1908. Adv. Sheets. 80 p., illus. 1910.

Williston soil was mapped as a loam in the Williams series and the Dickinson and Hettinger soils as loams in the Morton series.

PLAN OF THE EXPERIMENTS

These experiments were conducted on fields selected as typical of the localities and on soils as uniform as it was possible to obtain. The plats were one-tenth acre in size, 132 feet by 33 feet, separated by 1-rod roadways and 4-foot alleys. Uniform plans were followed at all stations. All plats of a given crop were planted on the same day with the variety best adapted to the locality. Other operations were uniform except where the plans of the experiment called for distinctive treatment. Figure 1 is a plan of the experiments at Dickinson, showing the cropping for the year 1923. Figure 2 is

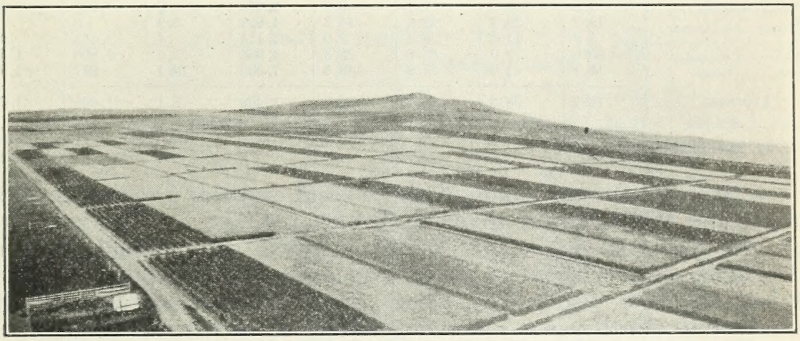

FIG. 2.—The experimental plats at Dickinson, N. Dak., looking toward the northwest. Photographed in 1923

from a photograph made in 1923 of the plats at Dickinson. The picture was taken from near the southeast corner, looking toward the northwest.

RESULTS OF THE EXPERIMENTS

The results of the experiments to determine the best methods of crop production might be considered by stations, by crops, or by methods. The last has been selected as the basis on which to outline their presentation. Some methods or practices, such as the use of green manures or sod crops in rotations, are considered separately, and others are considered in comparisons of two preparations that are more or less optional with the farmer or that might be substituted one for the other.

AVERAGE YIELDS

Each of the major crops—wheat, oats, barley, and corn—are grown on a considerable number of plats, embracing a wide range of methods, as will be shown in considering the effects of different treatments and preparations. The average yields of all the plats of each crop are fairly good indicators of the effects of the seasons on yields and of the yields that may be expected from the wide range of methods in use on farms.

TABLE 3.—*Average annual yields from all plats in the dry-land rotations at Dickinson, N. Dak., during the 17-year period from 1907 to 1923, inclusive*

Year	Wheat	Oats	Barley	Corn		Flax	Brome-grass	Alfalfa
				Grain	Fodder			
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Pounds*
1907	31.8	46.8	40.2	0	1,470	12.8		
1908	30.0	53.4	33.5	0	2,535	6.4	2,268	1,560
1909	36.0	67.8	46.4	50.0	5,815	13.4	3,102	3,425
1910	21.7	35.4	26.4	22.0	3,506	0	2,522	1,545
1911	5.9	8.9	9.0	0	4,070	0	748	710
1912	[1] 0	[1] 0	[1] 0	[1] 0	[1] 0	[1] 0	1,655	1,550
1913	25.9	55.5	31.2	27.6	3,589	8.6	2,665	2,320
1914	15.4	24.6	26.6	19.0	2,980	5.0	2,850	3,180
1915	37.0	93.4	57.0	0	3,330	30.7	2,440	3,260
1916	23.3	67.2	30.1	17.8	4,358	21.4	1,425	2,750
1917	12.6	17.9	10.8	0	1,316	1.6	2,500	1,750
1918	9.3	7.9	3.8	0	3,320	5.0	0	840
1919	3.8	3.0	1.2	9.7	2,074	.3	800	300
1920	19.2	38.7	25.6	14.3	4,958	5.3	0	0
1921	5.8	11.0	4.4	9.0	3,154	.4	1,135	455
1922	30.0	73.0	43.6	25.3	4,963	17.5	1,860	1,880
1923	18.1	45.9	27.9	48.5	7,535	10.1	667	2,900
Average	19.2	38.3	24.6	14.3	3,469	8.1	1,665	1,777

[1] Crop destroyed by hail in 1912.

The average annual yields of the several crops at Dickinson, Hettinger, and Williston are given in Tables 3, 4, and 5. The yields of flax are from a single plat on bromegrass sod at each station. Alfalfa is sown without a nurse crop and seldom produces a crop of hay the first year. The yields given are the averages of the second and third years. Bromegrass is seeded with wheat, and no crop of bromegrass hay is obtained the first year. The yields given for Dickinson and Hettinger are the averages of the hay crop in the second and third years. The yields in the second and third years at Williston are shown separately. At that station the yields beginning with those in 1915 are from slender wheatgrass. While the yields of alfalfa and bromegrass are from the second and third years of those crops in the rotations in which they occur, they are not always from second and third year sod, because a stand is not always obtained the first year.

TABLE 4.—*Average annual yields from all plats in the dry-land rotations at Hettinger, N. Dak., during the 12-year period from 1911 to 1922, inclusive*

Year	Wheat	Oats	Barley	Corn silage	Flax	Brome-grass	Alfalfa
	Bushels	*Bushels*	*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Pounds*
1911	0	0	0	0	0		
1912	16.6	23.5	24.8	[1] 5,019	10.0	980	0
1913	20.6	31.7	30.9	[1] 11,500	2.3	540	800
1914	10.9	31.4	14.9	8,679	3.4	1,126	2,350
1915	39.4	84.2	48.7	11,214	9.5	1,122	2,000
1916	5.0	44.2	20.1	6,438	5.4	2,684	1,190
1917	13.6	19.6	11.7	2,629	3.6	1,370	700
1918	14.3	18.6	25.9	4,760	6.4	526	0
1919	4.3	[2]	9.2	2,259	0	494	0
1920	13.8	37.0	31.9	6,555	7.5	0	1,150
1921	[2]	[2]	[2]	790	0	456	0
1922	20.4	34.1	32.3	10,570	10.0	972	1,845
Average	14.4	32.4	22.8	5,868	4.8	934	912

[1] Calculated from dry weight.

[2] Failure as a grain crop more or less complete on account of drought. Harvested for hay. The year is not included in obtaining the average.

The yields of all crops except corn averaged higher at Dickinson than at either of the other stations. The average yields of ear corn were practically the same at Dickinson and at Williston, but the yield of stover was somewhat higher at Dickinson. At Hettinger, beginning with 1914, the corn was harvested for silage and weighed green. The two crops obtained before that have been calculated to the same basis. The yields of corn at this station are the wet weights of the crop as harvested for silage and are not directly comparable with those from the other stations. The yields of corn at Dickinson and Williston are given as grain and as fodder, which is the total weight of ears and stover.

TABLE 5.—*Average annual yields from all plats in the dry-land rotations at Williston, N. Dak., for the 12-year period from 1909 to 1920, inclusive*

Year	Wheat	Oats	Barley	Corn		Flax	Bromegrass [1]	
				Grain	Fodder		Second year	Third year
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Pounds*
1909	27.5	65.3	43.4	18.5	6,718	12.2		
1910	1.8	3.5	1.4	0	1,791	0	0	0
1911	4.6	11.0	6.1	0	3,574	.9	0	630
1912	37.0	63.2	42.6	0	(2)	11.4	1,255	1,840
1913	15.2	37.8	19.1	25.4	(2)	0	830	290
1914	25.7	71.0	36.7	45.1	7,639	8.9	0	570
1915	24.1	46.1	27.9	0	2,419	7.0	650	495
1916	27.7	70.8	40.5	44.3	7,268	11.8	1,945	1,355
1917	10.3	17.1	12.2	5.1	2,919	0	500	410
1918	4.2	6.4	3.5	18.6	5,807	2.1	735	900
1919	4.0	6.0	4.1	9.7	2,778	3.4	0	0
1920	10.9	22.1	14.5	2.1	1,910	3.2	465	660
Average	16.1	35.0	21.0	14.1	4,282	5.1	580	650

[1] Slender wheatgrass beginning with 1915.
[2] Yield of fodder heavy, but weights as determined not considered reliable. Not included in calculating the average.

RESULTS WITH FALL PLOWING AND SPRING PLOWING COMPARED

The three stations permit several comparisons of the yields of small grains and corn on fall-plowed and on spring-plowed land. The average yields of the several crops with the two methods of preparation at each of the stations are assembled in Table 6 and shown graphically in Figure 3.

TABLE 6.—*Average yields of wheat, oats, barley, and corn on spring-plowed and on fall-plowed plats at Dickinson, Hettinger, and Williston, N. Dak., for the periods specified*

Crop and unit of measure	Dickinson, 1908 to 1923		Hettinger, 1912 to 1922		Williston, 1910 to 1920	
	Spring plowed	Fall plowed	Spring plowed	Fall plowed	Spring plowed	Fall plowed
Wheat, bushels	16.2	16.5	11.6	10.5	14.1	13.9
Oats, do	35.1	33.5	29.0	25.6	31.4	28.2
Barley, do	21.2	20.4	21.0	20.6	14.2	12.7
Corn:						
Grain, do	15.1	15.1	(1)	(1)	13.2	13.8
Fodder, pounds	3,707	3,277	6,004	6,344	3,514	3,542

[1] Corn yields at Hettinger are green weights as put into the silo, and averages are for the nine years from 1914 to 1922, inclusive.

The practice was to plow at seasonable times both in the spring and the fall. The average date of spring plowing was April 11 at Dickinson, April 13 at Hettinger, and April 14 at Williston. The date of fall plowing averaged September 13 at Dickinson, October 2 at Hettinger, and September 11 at Williston. Although these dates are no earlier than plowing is done on many farms, they are somewhat earlier than the average dates on which the operation is completed. Plats plowed in the fall were left rough over winter to prevent soil blowing and to hold snow. Seeding was done at the same time on both spring and fall plowing.

The differences in yields between crops grown on fall-plowed and on spring-plowed land at Dickinson were small. Wheat on fall

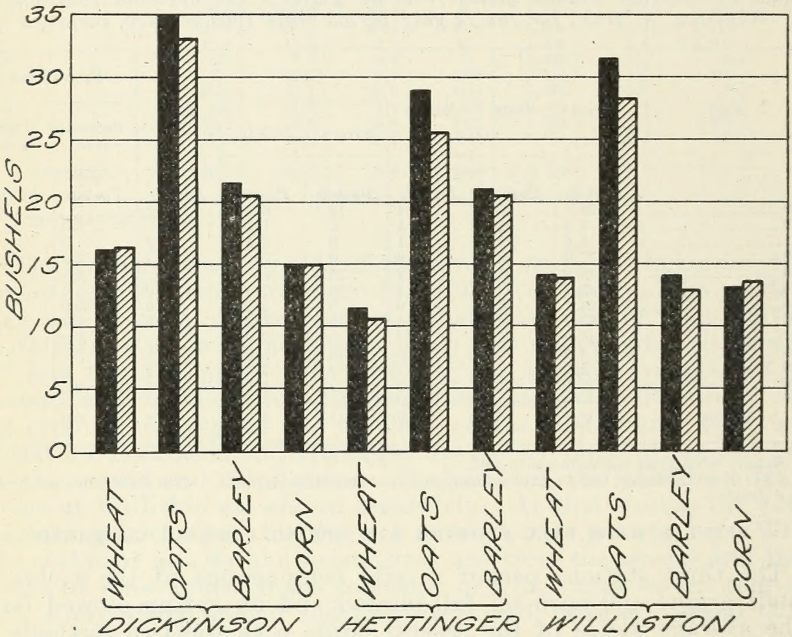

FIG. 3.—Average yields of wheat, oats, barley, and corn on spring-plowed and fall-plowed plats at Dickinson, Hettinger, and Williston, N. Dak. Spring plowing is shown by solid columns and fall plowing by slanting lines

plowing averaged 16.5 bushels to the acre and exceeded that on spring plowing by only 0.3 bushel. All other crops averaged higher on spring plowing than on fall plowing. Oats averaged 35.1 bushels on spring plowing and 33.5 on fall plowing, barley 21.2 bushels on spring plowing and 20.4 bushels on fall plowing, and corn 15.1 bushels of grain by each method and 3,707 pounds of fodder on spring plowing and 3,277 pounds on fall plowing.

A greater advantage is shown for spring plowing at Hettinger than at Dickinson. Wheat in one comparison averaged 11.6 bushels on spring plowing and 10.5 bushels on fall plowing. Two plats of wheat on spring plowing and two on fall plowing that can be compared for the period from 1917 to 1922, inclusive, when all crops generally were below the average in production, show an advantage of only 0.4 bushel in favor of spring plowing, the yields being 6.7 and 6.3

bushels. In the continuously cropped wheat series the spring-plowed plat averaged 11.8 bushels and the fall-plowed plat 8.9 bushels per acre for the 11 years from 1912 to 1922. Plats given similar treatment at Dickinson averaged 12.8 and 12.5 bushels, respectively, for a 15-year period.

Oats at Hettinger averaged 29 bushels on spring plowing and 25.6 bushels on fall plowing, an increase of 3.4 bushels with spring plowing. Barley averaged 21 bushels on spring plowing and 20.6 bushels on fall plowing, a difference of only 0.4 bushel. Corn averaged higher on fall plowing, but this method was represented by only a single plat. On plats cropped continuously to corn one that was spring plowed averaged 6,396 pounds and one that was fall plowed 7,021 pounds of silage per acre, an increase of 625 pounds, or almost 10 per cent, on fall plowing.

All crops at Williston except corn yielded slightly better on spring plowing than on fall plowing. The average yield of wheat was 14.1 bushels on spring plowing and 13.9 bushels on fall plowing. Oats averaged 31.4 bushels on spring plowing and 28.2 bushels on fall plowing. Barley averaged 14.2 bushels on spring plowing and 12.7 bushels on fall plowing. With corn, however, the yields of both grain and fodder were slightly heavier on fall plowing. Ear corn averaged 13.8 bushels on fall plowing and 13.2 bushels on spring plowing. Fodder averaged 3,542 pounds on fall plowing and 3,514 pounds on spring plowing.

The results are slightly in favor of spring plowing except for corn at Hettinger and Williston, where some increases have followed fall plowing. As a practice it is desirable to plow as much land in the fall as possible, in order that seeding may be done early in the spring. One of the most important factors in crop production in this area is the early seeding of grain. When the soil in the fall is wet enough to permit a good job of plowing, it is desirable to do it at that time. When the ground in the fall is so dry that plowing is difficult and the soil breaks up very rough, the succeeding yields are usually lower than on spring plowing. Usually the upper soil is wet enough in the spring to make a good job of plowing possible at that time.

RESULTS ON FALLOW AND FOLLOWING SMALL GRAINS COMPARED

At each of the stations fallow appears in a number of rotations and also in the continuous-cropping series with the principal crops. In the latter group of experiments fallow alternates with the several crops in two-year combinations. These rotations and cultural series give opportunity to study fallow with several crops and in several relations.

During the early years of the experiments the grain stubble was plowed in the fall in preparation for fallow and replowed during the summer of the fallow season. A series of tests of methods of fallow at several stations showed that fall plowing did not increase the yields. The present practice is to plow as early in the summer as practicable, usually between May 20 and June 15, and subsequently work the land only enough to prevent weed growth. Plowing is done to a depth of from 6 to 8 inches. Shallower plowing is practiced in the area but the best farmers plow to about this depth.

General experience indicates that deeper plowing is too expensive and in dry seasons may actually decrease yields, but in wet seasons it may be of benefit.

A comparison of yields on fallow and following small grains is of great importance in an area where a major part of the cropped land is in wheat, since much of the grain is necessarily on land that was in grain the previous year. Several rotations offer comparisons of the two methods. Grain stubble that is compared with fallow was plowed either in the fall or spring except a few plats at Hettinger, which were stubbled in for two seasons.

Yields of wheat, oats, barley, and corn following both small grain and fallow at the three stations are assembled in Table 7.

TABLE 7.—*Yields of wheat, oats, barley, and corn following fallow and following small grains at Dickinson, Hettinger, and Williston, N. Dak., for the periods specified*

Crop	Dickinson, 1908 to 1923				Hettinger, 1912 to 1922				Williston, 1910 to 1920			
	Following fallow		Following small grains		Following fallow		Following small grains		Following fallow		Following small grains	
	Number of plats	Bushels	Number of plats	Bushels	Number of plats	Bushels	Number of plats	Bushels	Number of plats	Bushels	Number of plats	Bushels
Wheat	3	21.5	3	15.9	8	16.9	[1] 2	10.4	3	18.0	5	14.0
Oats	3	45.5	8	36.0	5	35.4	[1] 6	25.9	3	40.0	8	28.1
Barley	1	26.6	1	20.8	1	28.6	[1] 2	20.9	1	28.7	[1] 3	13.7
Corn	1	17.4	20	14.9	1	[2] 5,627	18	[2] 6,028	1	18.9	16	13.1

[1] Includes two plats continuously cropped.
[2] Pounds green weight for silage. Average for nine years, from 1914 to 1922, inclusive.

At Dickinson three plats of wheat on fallow averaged 21.5 bushels and three on oat stubble 15.9 bushels, an increase of 5.6 bushels in favor of fallow. Three plats of oats on fallow averaged 45.5 bushels, and eight plats on small-grain stubble averaged 36 bushels, an increase of 9.5 bushels on fallow. A single plat of barley on fallow averaged 26.6 bushels and one on spring-plowed oat stubble 20.8 bushels, or 5.8 bushels more on fallow. A single plat of corn on fallow averaged 17.4 bushels, and 20 plats on small-grain stubble averaged 14.9 bushels. The results at Dickinson all show a decided increase in the yield of grains grown on fallow when compared with those grown on small-grain stubble.

A greater contrast in yields following the use of the two methods is shown at Hettinger than at Dickinson except for corn silage. Eight plats of wheat on fallow averaged 16.9 bushels, and two plats cropped continuously to wheat, one with spring and the other with fall plowing, averaged only 10.4 bushels. Oats averaged 35.4 bushels on five fallow plats and 25.9 bushels on six grain-stubble plats. Barley averaged 28.2 bushels on a single plat of fallow and 20.9 bushels on the spring-plowed and fall-plowed plats in the continuous-cropping series.

The yield of corn silage on a single plat grown on fallow averaged 5,627 pounds, and on 18 plats on grain stubble it averaged 6,028 pounds. Of these 18 plats 6 on spring-plowed wheat stubble averaged 6,133 pounds and 12 on spring-plowed oat stubble 5,976 pounds

of silage per acre. Although only a single plat of corn was grown on fallow, the result agrees with those of other stations in that the yield of corn stover or fodder with fallow is below that with other methods.

At Williston the contrasts in yields following the use of the two methods are about equal to those shown at Hettinger, with possibly a greater response to fallow. Wheat averaged 18 bushels on fallow and 14 bushels on grain stubble. Five plats were grown on grain stubble and three on fallow. Oats averaged 40 bushels on three fallow plats and 28.1 bushels on eight grain-stubble plats. Barley averaged 28.7 bushels on a single fallow plat and 13.7 bushels on grain stubble. Two of the three plats following grain were in the continuous-cropping series. A single plat on spring-plowed oats in rotation No. 7 averaged 15.3 bushels.

Corn shows a greater response to fallow at Williston than it does at Dickinson. During the 11 years of the experiments the average on fallow was 18.9 bushels and on grain stubble only 13.1 bushels.

RESULTS ON DISKED AND ON PLOWED CORN GROUND COMPARED

Corn ground usually was disked in preparation for small grains at each of the stations. At Dickinson corn ground was plowed in the spring in rotation No. 2, and the succeeding yield of wheat was 20.9 bushels; in rotations Nos. 3 and 62 it was fall plowed, and the average yields were 18.8 and 18.1 bushels, or an average of 19.3 bushels for the three plowed plats. All plats on disked corn ground averaged 19.7 bushels. A decrease in yield resulted from plowing corn ground.

At Williston wheat on single plats of spring-plowed and fall-plowed corn ground averaged 14.6 and 13.3 bushels, while seven plats on disked corn ground averaged 14.4 bushels. Two plats of oats on spring-plowed corn ground averaged 32.3 bushels, and four disked plats averaged 33.4 bushels. At both Dickinson and Williston a slight decrease resulted when small grains were grown on plowed rather than disked corn ground. Since disking is the cheaper method of preparation it is the one generally used. In this bulletin the results on disked corn ground are used in comparing corn ground with other preparations.

RESULTS ON FALLOW COMPARED WITH THOSE ON DISKED CORN GROUND

When the yields on disked corn ground and on fallow are compared they usually are favorable to fallow, but by a margin so small that when the whole farm scheme is considered the use of corn ground seems the more desirable.

At Dickinson the average yields of all plats with each method were: Wheat on fallow 21.5 bushels and on disked corn ground 19.7 bushels; oats on fallow 45.5 bushels and on disked corn ground 39.8 bushels; and barley on fallow 26.6 bushels and on disked corn ground 27.6 bushels. Wheat and oats are each on fallow and on disked corn ground in the two rotations, No. 18 (fallow, wheat, corn, and oats) and No. 19 (fallow, oats, corn, and wheat). The average yields of wheat in these rotations were 22.2 and 20.3 bushels, only 1.9 bushels greater on fallow. Oats averaged 46.8 bushels in rotation No. 19 and 42.8 bushels in rotation No. 18, or 4 bushels more on the fallow.

Another comparison of wheat on fallow and on corn ground can be made in rotations Nos. 5 and 3. In rotation No. 5 (fallow, wheat, and oats) wheat is on fallow, and in rotation No. 3 (corn, wheat, and oats) it follows corn. The average yield was 21.7 bushels in rotation No. 5 and 18.8 bushels in rotation No. 3, or 2.9 bushels in favor of the fallow. Oats in the two rotations averaged 35.2 and 34.5 bushels, slightly the better in the rotation containing fallow. Rotations Nos. 8 and 4 are similar to Nos. 5 and 3 except that the places of oats and wheat are reversed. Oats after fallow in rotation No. 8 (fallow, oats, and wheat) averaged 44.3 bushels and after corn in rotation No. 4 (corn, oats, and wheat) 39.8 bushels, or 4.5 bushels more after the fallow. The yield of wheat in the two rotations was 16.6 and 16.1 bushels, or 0.5 bushel more in the one containing fallow.

The average yield of corn in rotation No. 3 was 14.4 bushels of grain and 3,199 pounds of fodder, and in rotation No. 4 it was 13.8 bushels of grain and 3,204 pounds of fodder.

At Hettinger wheat on fallow in rotation No. 18 averaged 17.4 bushels, and following corn in rotation No. 19 it averaged 16.8 bushels, or less than 1 bushel in favor of fallow. In these same rotations oats following corn averaged 32.3 bushels and following fallow 31.4 bushels, or 0.9 bushel more after corn. All wheat on fallow at Hettinger averaged 16.9 bushels and all on disked ground 15.4 bushels. Five plats of oats on fallow averaged 35.4 bushels, and six plats on disked corn ground averaged 32.2 bushels.

At Williston the spread between the yields of grains on disked corn ground and on fallow was greater than at the other stations. Spring wheat averaged 18 bushels on three fallow plats and 14.4 bushels on seven disked corn plats, or 3.6 bushels in favor of fallow. The increase with oats was from 33.4 bushels on disked cornland to 40 bushels on fallow. Barley averaged 28.7 bushels on fallow and 23.8 bushels on disked corn ground in rotation No. 6. In rotations Nos. 18 and 19 the average increase in the yield on fallow over that on disked corn ground was 4.1 bushels of wheat and 11.2 bushels of oats. In rotations Nos. 5 and 3 the yield of wheat was 3.1 bushels greater on fallow than on disked corn ground, and in rotations Nos. 8 and 4 the increase of oats after fallow was 1.8 bushels.

The comparisons cited indicate that, measured by yield, fallow has some advantage over disked corn ground as a preparation for small grains at the three stations, the advantage being greatest at Williston. The response is about equal in degree for each of the small-grain crops. At Dickinson there is some indication that a small effect is seen in the second crop after fallow, but if present at all it is very slight. The small increase in grain yields which results from fallow would not offset the value of a corn crop which averages about 15 bushels of grain, or 3,500 pounds of grain and stover, or over 3 tons of silage. The cost of raising the corn crop is very little more than that of handling bare fallow.

The choice between fallow and corn or the relative areas of each on a farm must depend on several factors. As a matter of crop insurance both should be included wherever possible. The chances for a good yield of most crops are increased by the use of fallow, but are increased nearly as much when corn takes the place of the fallow. Corn should be grown to the extent that it can be handled to advantage and fed to livestock. If a straight grain-farming

system is practiced, the acreage of corn should be less than if livestock is grown. With the more general use of adapted seed, better yields of corn can be expected.

RESULTS ON FALLOW COMPARED WITH THOSE ON DISKED POTATO GROUND

Two four-year rotations at Hettinger offer comparisons of both wheat and oats following potatoes and following fallow. Rotation No. 75 is manured fallow, wheat, potatoes, and oats, and rotation No. 76 is manured fallow, oats, potatoes, and wheat. Wheat on potato ground averaged 0.3 bushel more than on fallow, and oats following potatoes averaged 0.1 bushel less than on fallow. Potatoes averaged 82.8 bushels in rotation No. 75 and 82.1 bushels in rotation No. 76, indicating that the two were about equal in yielding power. Since the two rotations differed so little in the yields of both wheat and oats the conclusion is that potato ground is equal to fallow as a preparation for grain. These rotations were arranged to determine the relative effects of potatoes and of fallow on succeeding grain crops and not to study the method of growing potatoes. During dry years potatoes will yield more on fallow, but in years with low temperatures and heavy rainfall potatoes, like corn, may yield less after fallow than following grains. In 1923 some experiments were added at Dickinson to determine the relative values of grain stubble and of fallow for the production of potatoes. It is too early to draw conclusions from the results.

RESULTS ON MANURED FALLOW COMPARED WITH THOSE ON UNMANURED FALLOW

Four rotations at Hettinger included fallow which received an application of manure just before plowing in the spring of the fallow year. Two of these may be compared with similar rotations containing fallow without manure. Rotations Nos. 19 and 71 are fallow, oats, corn, and wheat, with manure applied at the rate of 10 tons per acre before the fallow in rotation No. 71. A comparison of the yields of oats in these two rotations shows that there was a decrease of 1 bushel per acre following the use of manure. The annual differences in yield were marked by wide variations in favor of both the manured and the unmanured fallow. In 1913 oats in rotation No. 19 yielded 41.9 bushels and in rotation No. 71 only 15 bushels, or 26.9 bushels in favor of the unmanured fallow. In 1915 rotation No. 19 yielded 83.4 bushels and rotation No. 71 105 bushels, or 21.6 bushels in favor of the manured fallow. The average weight of straw was 275 pounds heavier in rotation No. 19 than in No. 71. Wheat following corn in these rotations averaged 2.7 bushels more in the unmanured than in the manured rotation. Manure induces a rank early growth, and these experiments indicate that the yield is increased in wet years, when there is ample moisture to carry the vigorous early growth to maturity.

Rotations Nos. 18 and 72 are similar to the above rotations except that wheat instead of oats immediately follows the fallow. The wheat averaged 17.4 bushels after ordinary fallow and 15.4 bushels after manured fallow, a decrease of 2 bushels following manure. The weight of straw was 129 pounds heavier on the manured fallow. In all of these rotations corn was the second crop after the fallow and was harvested for silage. The green weight of corn harvested for silage averaged 587 pounds per acre less following wheat in the

manured rotation, No. 72, than in the unmanured rotation, No. 18; and following oats it averaged 373 pounds per acre more in the manured rotation, No. 71, than in the unmanured rotation, No. 19.

RESULTS WITH WHEAT ON DISKED STUBBLE

The practice of seeding wheat on unplowed stubble with or without previous disking or other tillage before seeding is very general in certain sections of the northern Great Plains. In Canada this system is most often used the second year after fallow, but it may follow a crop grown on either fall or spring plowing. In some cases several crops in succession may be stubbled in.

Wheat was seeded on stubble only at Hettinger. Three plats, known as rotation No. 583, were cropped to wheat. On one of these each year the wheat was on fall plowing, on another it was on disked wheat stubble the second crop after plowing, and on the last it was on disked wheat stubble the third crop after plowing. This rotation was started in 1916, and six years' results are available. The fall-plowed plat exceeded the others in yield of grain only once, the first-year disked stubble yielded highest four times, and once the second-year stubble was best. The six-year average yield of the three treatments was: Fall plowed, 8 bushels of grain and 948 pounds of straw; first-year disked, 10.4 bushels of grain and 1,017 pounds of straw; and second-year disked, 9.6 bushels of grain and 1,037 pounds of straw. During the unfavorable seasons of 1919 and 1921, when all yields were very low, and in 1922, when the highest yields were obtained, the disked plats exceeded the fall-plowed one.

Rotation No. 582 is a two-year rotation of wheat on fall plowing and wheat on disked wheat stubble. In this rotation the six-year average yield on the fall plowing exceeded that on disking by 1.1 bushels, the yields being 4.5 and 3.4 bushels, respectively. There were two years of complete failure. For the same period the plat of continuous wheat on fall plowing averaged 5.6 bushels per acre.

The single plat known as rotation No. 581 grew wheat continuously without plowing for the six years from 1917 to 1922 and averaged 4.5 bushels per acre. In 1922 it produced at the rate of 12.7 bushels of grain and 640 pounds of straw, compared with 13.5 bushels of grain and 1,890 pounds of straw on the spring-plowed plat in the continuous-cropping series. The latter plat averaged 5.6 bushels per acre for the six years from 1917 to 1922. Rotations Nos. 581 and 582 are located some distance from rotation No. 583 and are not directly comparable with it.

The results of these experiments are perhaps more favorable to disking than those of more extensive trials would be, but they are in general accord with the results of similar experiments at other stations on the northern Great Plains. The yields of wheat on disked stubble the second year after fallow or plowing generally are decreased somewhat but not sufficiently to condemn this system of cropping. The practice has the advantage of reduced cost, but the danger lies in the tendency to continuous cropping until the land becomes infested with weeds.

RESULTS WITH GREEN MANURES

Rotations containing rye, field peas, and sweet clover as green-manure crops were included at each of the stations. These crops

were turned under at their maximum growth and the land kept free from weeds during the remainder of the season and cropped to either wheat or oats the following year. This method of handling the green manure made it more comparable to fallow than to any other tillage method. Fallow plats as a rule were plowed early enough to prevent much loss of moisture by weed growth, but in many seasons the growth of rye, peas, or sweet clover for green manure almost or entirely exhausted the available soil water by plowing time. The average dates of plowing fallow and the green-manure crops were: Fallow, June 21; rye, July 1; peas, July 11; and sweet clover, July 6. During the five-year period from 1919 to 1923 the average date of plowing fallow at Dickinson was June 5, showing the general adoption there of the more recent practice of early plowing. In experiments on the time of plowing fallow conducted at other stations, delayed plowing shows reduced yields, which correspond very closely to those which follow the late plowing of green-manure crops.

The green-manure rotations are as follows:

No. 14, Rye, oats, corn, and wheat.
No. 15, Rye, wheat, corn, and oats.
No. 16, Peas, oats, corn, and wheat.
No. 17, Peas, wheat, corn, and oats.
No. 31, Sweet clover, oats, corn, and wheat.
No. 32, Sweet clover, wheat, corn, and oats.
No. 61, Peas, wheat, and oats.
No. 63, Rye, wheat, and oats.

All of these were included in the experiments at Dickinson, all but the last two at Hettinger, and all but the last three at Williston.

Other rotations previously described containing fallow are directly comparable with these containing green manure. Rotation No. 18 is fallow, wheat, corn, and oats and rotation No. 19 fallow, oats, corn, and wheat. Rotation No. 5 is a three-year rotation containing wheat on fallow and oats on fall-plowed wheat stubble, and rotation No. 8 is a similar rotation in which the oats are on fallow and are followed by wheat.

Small grains, the first crop following green manure, averaged less than following bare fallow, the method most comparable with green manure, and with the exception of oats at Dickinson and wheat at Williston the yields were less than on disked corn ground. Table 8 shows that wheat averaged 16.5 bushels on disked corn ground, 18.8 bushels on fallow, and 15.8 bushels following green manure at the three stations. Oats in a similar comparison averaged 35.1 bushels on disked corn ground, 40.3 bushels on fallow, and 33.9 bushels after green manure.

A legume has been of no more value than a nonlegume for plowing under. The yields of wheat after both peas and sweet clover were slightly less than after rye, but the differences were too small to be significant. At Dickinson oats after rye averaged 40.7, after peas 37.7, and after sweet clover 39.2 bushels per acre. At Hettinger the average after rye was 29.8, after peas 27.2, and after sweet clover 31.7 bushels, indicating a slight advantage for sweet clover. The yield of corn silage at Hettinger also was higher in the sweet-clover rotations.

TABLE 8.—*Average yields of wheat, oats, and barley on disked corn ground, fallow, and green-manured land at Dickinson, Hettinger, and Williston, N. Dak., for the periods specified*

[Yields in bushels per acre]

Crop	Dickinson, 1908 to 1923			Hettinger, 1912 to 1922			Williston, 1910 to 1920		
	Disked corn	Fallow	Green manure	Disked corn	Fallow	Green manure	Disked corn	Fallow	Green manure
Wheat	19.7	21.5	17.4	15.4	16.9	13.2	14.4	18.0	16.7
Oats	39.8	45.5	42.0	32.2	35.4	26.9	33.4	40.0	32.9
Barley	27.6	26.6	----	----	28.6	----	23.8	28.7	----

There seems to be no evidence of a cumulative effect of green manure. The relative yields of corn the second year after fallow and after green manure did not change during the periods of the experiments. During the four-year period from 1917 to 1920, when corn yields were low, the yield of corn fodder was lower after green manure than after fallow. In similar experiments at Edgeley, N. Dak.,[3] a tendency toward increased yields of corn in the rotations containing sweet clover as a green manure was noted during the later years of their history.

Since green-manure crops require an added expense for seed and seeding and the benefits to subsequent crops are negligible, there is no economic basis for their use. Possibly a longer history may bring out benefits which have not yet become apparent.

RESULTS WITH SOD CROPS

In more humid regions sod crops generally benefit succeeding crops, particularly if the sod crop be a legume. Results of these experiments indicate that in this district the yields of grain following sod are lower than following either corn or fallow and that there is no significant difference in the yields following alfalfa and bromegrass.

Three sod crops were included in the rotations at Dickinson and at Hettinger and two at Williston. At Dickinson bromegrass is included in rotations Nos. 10 and 12, alfalfa in No. 42, and sweet clover in No. 11. At Hettinger bromegrass was in rotations Nos. 12 and 41, alfalfa in No. 42, and sweet clover in No. 11. At Williston bromegrass was in rotations Nos. 10 and 12. The details of the sod rotations are as follows:

No. 10, Bromegrass, bromegrass, oats, corn, and wheat.
No. 12, Bromegrass, bromegrass, flax, oats, corn, and wheat.
No. 41, Bromegrass, bromegrass, bromegrass, oats, corn, and wheat.
No. 11, Sweet clover, sweet clover, oats, corn, and wheat.
No. 42, Alfalfa, alfalfa, alfalfa, oats, corn, and wheat.

The bromegrass was sown in the spring with the wheat. This method of seeding has the advantage of avoiding the loss of the use of the land for a season. A full stand usually did not develop until the plants spread in the second year. In several dry years the stand was lost and reseeding was necessary. At Williston slender wheatgrass was substituted for the bromegrass in rotations

[3] Cole, J. S. Crop rotation and cultural methods at Edgeley, N. Dak. U. S. Dept. Agr. Bul. 991, 24 p., illus. 1921.

Nos. 10 and 12 beginning with 1915. The yields of bromegrass for the second and third years were 1,134 and 2,246 pounds at Dickinson, 664 and 1,218 pounds at Hettinger, and 580 and 650 pounds at Williston.

Alfalfa is sown in the spring on fall-plowed wheat stubble and stands two years in addition to the year of seeding. A crop is seldom obtained the first year. At Dickinson first-year alfalfa during 16 years averaged 339 pounds; second-year, 1,749 pounds; and third-year, 1,804 pounds. At Hettinger alfalfa averaged 169 pounds the year of seeding, the second year 757 pounds, and the third year 1,067 pounds. The lighter average yield of the second year in comparison with the third is largely owing to the fact that a stand is not always obtained the first year. In such cases the second year is actually a first-year crop. To this extent the average yields may be somewhat lighter than should be expected from an established sod in this district.

The plan of rotation No. 11 was to sow red clover in the spring on fall-plowed wheat stubble. Red clover, however, winterkilled so frequently that it was replaced by sweet clover in recent years; but they were dry years in which it was particularly difficult to obtain stands, and the results were not conclusive.

The yields of oats, corn, wheat, and flax in rotations containing sod crops are assembled in Table 9.

TABLE 9.—*Average yields of oats, corn, wheat, and flax in sod rotations at Dickinson, Hettinger, and Williston, N. Dak., for the periods specified*

Station and sod crop	Rotation number	Oats		Corn [1]		Wheat		Flax	
		Grain	Straw	Grain	Stover	Grain	Straw	Grain	Straw
Dickinson, 1908 to 1923:		*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Bushels*	*Pounds*
Bromegrass	10	39.4	1,648	16.5	2,581	20.6	2,316		
Do	12	33.3	1,355	15.3	2,353	18.1	1,912	7.9	1,167
Average		36.4	1,501	15.9	2,467	19.4	2,114	7.9	1,167
Alfalfa	42	34.9	1,534	14.0	2,614	17.9	1,952		
Clover	11	34.3	1,541	13.1	2,254	17.4	1,827		
Hettinger, 1912 to 1922:									
Bromegrass	12	24.8	1,583		6,038	14.9	2,125	5.3	1,154
Do	41	27.4	1,716		5,954	15.9	2,253		
Average		26.1	1,650		5,996	15.4	2,189	5.3	1,154
Alfalfa	42	28.4	1,916		5,164	20.2	2,991		
Clover	11	22.4	1,523		6,586	14.4	2,371		
Williston, 1910 to 1920:									
Bromegrass	10	29.3	1,591	11.1	2,894	13.8	1,360		
Do	12	22.1	1,035	11.3	2,889	14.7	1,224	4.4	500
Average		25.7	1,313	11.2	2,892	14.3	1,292	4.4	500

[1] Yields of corn at Hettinger are total wet weights as harvested for silage.

At Dickinson oats on fall-plowed bromegrass sod in rotation No. 10 averaged 39.4 bushels. This rotation is favored to some extent by its location, and the yields of all grain crops are higher in it than in rotation No. 12. In rotation No. 12 flax follows the bromegrass, and the oats are on fall-plowed flax stubble. Oats in this rotation averaged 33.3 bushels, or 6.1 bushels less than in rotation No. 10. The average of the oats in the two rotations was 36.4 bushels. Two plats of oats on fall-plowed wheat stubble in

the three-year rotations averaged 35.4 bushels and two on spring-plowed corn ground 35.3 bushels. Comparison of these yields with those in rotations containing sod shows an increase of about 1 bushel of oats to the acre in the sod rotations, a quantity so small that it is of doubtful significance. It may be repeated here that at Dickinson oats on disked corn ground averaged 39.8 bushels, on green manure 42 bushels, and on fallow 45.5 bushels, yields all well above those on sod.

Wheat on disked corn ground in rotations Nos. 10 and 12 averaged 20.6 and 18.1 bushels, or 19.4 bushels for the two. This is 0.3 bushel less than the average of all wheat at Dickinson on disked corn ground and 2.1 bushels less than wheat on fallow. Wheat on disked corn ground the third year after alfalfa in rotation No. 42 averaged 17.9 bushels.

Flax on bromegrass sod in rotation No. 12 at Dickinson averaged 7.9 bushels during the 16 years. A maximum of 30.7 bushels was obtained in 1915. There were three total failures, and in two years yields of less than 1 bushel per acre were obtained. Flax in this rotation at Hettinger averaged 5.3 bushels. There were two total failures, and a maximum yield of 10 bushels was obtained in 1912 and in 1922. At Williston the average yield was 4.4 bushels with three complete failures and a maximum of 11.8 bushels in 1916.

The yields were affected to only a very limited extent by wilt or other disease. At Dickinson in 1923 in the third round of the rotation only 2 per cent of the plants were killed by wilt.

Weeds have been a much greater factor than disease in reducing the yields of flax. The worst of these has been Russianthistle. A sod rotation has not noticeably decreased infestation of this weed; but, since the plats are small, the seed is scattered over them by the wind more than it would be in a larger area. Bromegrass has not been killed completely in wet years and by using the moisture has further reduced the yields of flax. In the earlier years the sod was broken in the spring shortly before seeding the flax. This practice has been changed to breaking some time after the bromegrass is harvested the previous summer, and much better results have followed.

Oats at Hettinger on bromegrass sod averaged 27.4 bushels in rotation No. 41 and 24.8 bushels in rotation No. 12, or 26.1 bushels for the two. Following alfalfa in rotation No. 42 the average was 28.4 bushels, or 2.3 bushels more than following the bromegrass. Oats following clover in rotation No. 11 averaged only 22.4 bushels. The clover failed so consistently that it can not be considered that the oats were grown on sod. On disked corn ground and fallow the averages were 32.2 and 35.4 bushels, respectively.

The difference between the yields following alfalfa and following bromegrass may be owing to other factors than the differences in the sod crops. Corn silage in the alfalfa rotation yielded 832 pounds less than in the bromegrass rotation, but wheat yielded 4.8 bushels more. In a similar comparison at Dickinson wheat in the alfalfa rotation was exceeded by that in the bromegrass rotation by 1.5 bushels per acre.

At Williston oats after bromegrass in rotations Nos. 10 and 12 averaged 29.3 and 22.1 bushels, or 25.7 bushels for the two rotations. Oats at this station on spring-plowed grain stubble averaged

31.4 bushels and on fall-plowed grain stubble 28.2 bushels. Corn in the sod rotations averaged less than on either spring plowing or fall plowing in other rotations. Wheat after bromegrass averaged 13.8 bushels in rotation No. 10 and 14.7 bushels in rotation No. 12, or 14.3 bushels for the two. The average yield of wheat on seven disked corn plats was 14.4 bushels, so there is no benefit apparent from the sod crops.

When all factors are considered it is not clear that alfalfa in a rotation on dry lands benefits the succeeding crop to any extent. In similar experiments under irrigation a substantial benefit follows alfalfa.

RESULTS WITH CONTINUOUS CROPPING

A series of plats cropped continuously to wheat, oats, barley, and corn is included at each of the three stations. In this series each crop occupies four plats. Plot A bears the same crop each year on shallow spring plowing. Plat B is an adjacent plat continuously cropped on fall plowing. Plats C and D alternate with the crop and fallow.

Average yields of the continuously cropped series for the period of the experiments at each station are assembled in Table 10. With the exception of corn, the yields on the continuously cropped plats are distinctly lower than the yields in rotations with other crops or after fallow. As an example, wheat at Dickinson on plat A, spring plowed, and plat B, fall plowed, averaged 12.7 and 12.5 bushels, respectively. All wheat in the rotations averaged 18.4 bushels, an increase of 5.7 bushels, or almost 45 per cent more than the continuously cropped plat on spring plowing. Wheat on the C and D plats on fallow averaged 20.9 bushels, an increase of 8.2 bushels, or 65 per cent, more than the spring-plowed plat.

Almost as great a relative decrease occurred at Dickinson when oats were continuously cropped. The A and B plats in the continuous series averaged 27.5 and 27.8 bushels, respectively. All oats in the rotations averaged 37.7 bushels and on the C and D plats on fallow 45.5 bushels. Thus the A plat, spring plowed and cropped continuously, yielded 10.2 bushels less than the average of all plats and 18 bushels less than on alternate fallow.

TABLE 10.—*Average yields of wheat, oats, barley, and corn continuously cropped on spring plowing, fall plowing, and on fallow at Dickinson, Hettinger, and Williston, N. Dak., for the periods specified*

Station, years grown, plat, and method	Wheat	Oats	Barley	Corn [1]	
				Grain	Fodder
Dickinson, 1908 to 1923:	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Pounds*
A, spring plowed	12.7	27.5	21.4	16.9	3,343
B, fall plowed	12.5	27.8	20.5	16.5	3,305
C and D, fallow	20.9	45.5	26.6	17.4	3,248
Hettinger, 1912 to 1922:					
A, spring plowed	11.5	31.0	21.4	----------	6,396
B, fall plowed	8.9	31.1	20.7	----------	7,021
C and D, fallow	16.9	42.9	28.6	----------	5,627
Williston, 1910 to 1920:					
A, spring plowed	12.1	23.2	13.0	15.8	4,947
B, fall plowed	11.5	24.0	13.1	15.6	5,093
C and D, fallow	18.6	40.6	28.7	18.9	6,209

[1] Yields of corn at Hettinger are total wet weights as harvested for silage.

With barley at Dickinson the relative decrease with continuous cropping was not quite so great as with oats and wheat. Plats A and B averaged 21.4 and 20.5 bushels, while on the fallow plats C and D the average was 26.6 bushels. The average of the five plats of barley grown in the rotations was 23.7 bushels. The A plat yielded 5.2 bushels less than the plat on alternate fallow and 2.3 bushels less than the average of five plats. The low average of barley in relation to the average yield of oats and wheat is owing to the fact that since only five plats are grown the two continuously cropped plats reduce the average.

At Hettinger the reduction in yields of the small grains by continuous cropping was very similar to that at Dickinson. Wheat on plats A and B averaged 11.5 and 8.9 bushels, respectively, and on fallow on plats C and D 16.9 bushels. Oats on plats A and B averaged 31 and 31.1 bushels, respectively, and on fallow 42.9 bushels. Barley on the spring-plowed and fall-plowed plats A and B averaged 21.4 and 20.7 bushels and on C and D 28.6 bushels.

Continuously cropped small grains at Williston show a greater contrast with the yields after fallow than is shown at either of the other stations. On the A and B plats in the wheat series the yields were 12.1 and 11.5 bushels, respectively, for the spring-plowed and fall-plowed plats and 18.6 bushels on fallow. Oats on the A plat averaged 23.2 bushels, on the B plat 24 bushels, and on the C and D plats on fallow 40.6 bushels. Barley on the A plat averaged 13 bushels, on the B plat 13.1 bushels, and on the C and D plats 28.7 bushels.

Continuous cropping to corn has resulted in increased yields in contrast to the decrease noted for all small grains. The increased yield of grain on the continuously cropped corn plats has been consistent throughout the period of the experiments. Like the small grains, there was little difference between the average results on spring plowing and fall plowing, and there was also a response to fallow. At Dickinson continuous corn on spring plowing averaged 16.9 bushels, on fall plowing 16.5 bushels, and on fallow 17.4 bushels. At Williston continuous corn on spring plowing averaged 15.8 bushels, on fall plowing 15.6 bushels, and on fallow 18.9 bushels.

Although the yields of ear corn have been greater on continuous cropping, there was a reduction in the quantity of fodder produced at Dickinson. The yield of fodder was 3,343 pounds on spring plowing, 3,305 pounds on fall plowing, and 3,248 pounds on fallow, all below the average of all plats in the rotations. At Williston the three continuously cropped plats were above the average of all plats. The average on spring plowing was 4,947 pounds, on fall plowing 5,093 pounds, and on fallow 6,209 pounds. At Hettinger the yields of green corn for silage were 6,396 pounds on spring plowing, 7,021 pounds on fall plowing, and 5,627 pounds on fallow, the latter weight being below the average of all plats.

A definite decrease in the production of small grains occurs when these crops are grown continuously. This decrease is greater in some years than others, owing to the response to tillage and to seasonal variation, but has been consistent through the later years of the experiments. From all evidence the decrease is due to weeds in these plats rather than to lack of fertility or other causes. At

Dickinson, where the experiments have run longest, a marked reduction in the yield of wheat was noted but not in the yield of ear corn. From the A plat at this station an average of 762 pounds of wheat and 1,189 pounds of straw, a total of 1,951 pounds, was removed annually by the wheat crop. In the corn series 3,343 pounds of fodder was removed annually, or more material than was removed from the wheat plats if the two weights were adjusted to a dry basis. Since the corn plat is free from weeds and the wheat plat is badly infested, it is inferred that weeds are responsible for the decreased yield of wheat.

The plats alternately cropped to small grains and fallowed have remained relatively free from weeds, and the yields of these plats have not decreased in comparison with those of similar ones in rotations.

SUMMARY

This bulletin summarizes the results of the tillage experiments and crop rotations in western North Dakota during 16 years at Dickinson and 11 years each at Hettinger and Williston.

Climatic conditions at the three stations are very similar, the precipitation being a little greater at Dickinson and slightly better distributed at Hettinger, and the frost-free period longer at Williston.

The results of most of the experiments agree very closely at the three stations and also agree with the results of similar work at other stations in the northern Great Plains.

Spring grains and corn have produced slightly higher yields with spring plowing than with fall plowing. Exceptions to this are noted with wheat at Dickinson, corn silage at Hettinger, and both ear corn and fodder at Williston.

At each of the stations the highest average yields of all crops, except barley and corn fodder at Dickinson and corn silage at Hettinger, were obtained on fallow. The increases over other methods were not sufficiently great, however, to pay directly for the use of the land for a season and for the tillage necessary to keep the fallow clean. As a factor in keeping land free from weeds and as an aid to early seeding, fallow has a value not directly estimable.

Disking corn ground is more economical than either spring plowing or fall plowing it in preparation for small-grain crops and has given higher yields.

The value of corn in a rotation is far greater than the value of the feed produced. Yields of wheat, oats, and barley were greater on disked corn ground than on spring-plowed or fall-plowed grain stubble and not far below those on fallow. Wheat at the three stations averaged 18.8 bushels on fallow and 16.5 bushels on disked corn ground, oats averaged 40.3 bushels on fallow and 35.1 bushels on disked corn ground, and barley averaged 28 bushels on fallow and 25.7 bushels on corn ground.

Growing corn on fallow has resulted in an increase of mature ear corn, but a reduction in the quantity of fodder at Dickinson, a reduction in the silage at Hettinger, and an increase in the fodder at Williston. Corn on fallow tends to mature later than when grown on grain stubble plowed either in the fall or in the spring.

Disked potato ground was as good as corn ground and almost as good as fallow as a preparation for small grains.

Manure applied to fallow before plowing in the spring of the fallow year did not increase grain yields during the 11 years of the experiment at Hettinger. There was a tendency in wet years toward an increase and in dry years toward a decrease in the yield of wheat and oats. There was no increase in the weight of corn silage the second year after manure. In a single three-year rotation at Dickinson manure applied before corn increased the yield of fodder about 25 per cent, but it did not increase either the wheat or the oats in the second and the third years of the rotation.

Seeding wheat on disked wheat stubble can not be condemned on the basis of these experiments. The yields on both first-year and second-year disking exceeded those on fall plowing during a six-year test at Hettinger. Sowing wheat on disked stubble frequently reduces yields through an increase of weeds and the resulting loss of moisture.

Plowing under green-manure crops did not result in an increase in the yields of grain crops immediately following or of other crops in the rotations over those in similar rotations containing fallow instead of green manure. While the method of handling the green manure makes the results more comparable with fallow than with other methods, the yields have been slightly less and the expense greater by the cost of seed and seeding. There seems to be no cumulative effect from the green manure, and a legume is of no more value than a nonlegume.

Bromegrass and alfalfa are recognized as the most productive perennial hay plants available for the area, but are of doubtful utility in short rotations. No measurable benefit to succeeding grain yields can be noted as an effect of sod. Difficulty in securing stands under the conditions of the experiments reduced the yields of hay below a profitable point for the period the land was occupied. Where a stand is established it should be allowed to remain for several years rather than plowed up with the hope of benefiting succeeding grain crops.

Continuous cropping to wheat, oats, and barley on spring plowing and on fall plowing resulted in marked reductions in the yields of those crops. This reduction appears to be the result of weeds rather than of a decrease in the fertility of the soil. Continuous cropping to corn increased the yield of mature grain and of fodder at Williston and of silage at Hettinger, but it slightly decreased the quantity of fodder at Dickinson.